Morris, R. J., Lockwood, A. P. M. & Dawson, M. E. (1982b). An effect of acclimation salinity on the fatty acid composition of the gill phospholipids and water flux of the amphipod crustacean *Gammarus duebeni*. *Comp. Biochem. Physiol.* **72A**, 497-503.
Renfro, J. L., Schmidt-Nielsen, B., Miller, D., Benos, D. & Allen, J. (1974). Methylmercury and inorganic mercury: uptake and distribution and effect on osmoregulatory mechanisms in fishes. In *Pollution and Physiology in Marine Organisms* (F. J. Vernberg and W. B. Bernberg, eds.), pp. 101-122. Academic Press, New York.
Sargent, J. R. (1976). The structure, metabolism and function of lipids in marine organisms. In *Biochemical and Biophysical Perspectives in Marine Biology* (D. C. Malins and J. R. Sargent, eds.), pp. 369-432. Academic Press, London.
Schmidt-Nielsen, B., Sheline, J., Miller, D. S. & Deldonno, M. (1977). Effect of methylmercury upon osmoregulation, cellular volume, and ion regulation in winter flounder, *Pseudopleuronectes americanus*. In *Physiological Responses of Marine Biota to Pollutants* (F. J. Vernberg, A. Calabrese, F. P. Thurberg and W. B. Vernberg, eds.), pp. 105-117. Academic Press, New York.
Somero, G. N. & Hochachka, P. W. (1976). Biochemical adaptations to temperature. In *Adaptations to Environment. Essays on the Physiology of Marine Animals* (R. C. Newell, ed.), pp. 125-190. Butterworths, London.

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# Drift Plastic—An Expanding Niche for a Marine Invertebrate?

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**Beach collection of plastic litter washed ashore at Fort Pierce on the Atlantic coast of Florida showed that, while some of this material may have had a local source, much of the rest originated in the Caribbean. During its pelagic existence the plastic commonly became encrusted by marine organisms. In contrast to the diverse assemblage of organisms associated with pelagic *Sargassum*, however, the number of species encrusting drift plastic was limited, being dominated primarily by the colonies of the bryozoan, *Electra tenella*, an organism which may be increasing its abundance and distribution, due to increasing amounts of drift plastic substrata.**

Strong onshore winds or storms, particularly in winter months, cast tons of *Sargassum* ashore on Florida's Atlantic coast. Entangled with the masses of weed and its associated community, are other pelagic organisms, *Physalia* and (more rarely), *Velella* and *Janthina*, as well as large quantities of tar (the subject of much recent study, e.g. Butler *et al.*, 1973; Cordes *et al.*, 1980; Van Dolah *et al.*, 1980) and an amazing amount of plastic trash, often encrusted with sessile organisms.

The amount of plastic produced worldwide has increased enormously over the last 30 years (Carpenter & Smith, 1972). It is not known how much of this eventually ends up in the oceans, but there is no doubt that plastic pellets and spherules now occur in areas far removed from shore sources or major shipping lanes (Venrick *et al.*, 1973; Morris, 1980b), and that chemicals derived from plastics have become incorporated into the bodies of marine organisms (Fowler & Elder, 1978; Giam *et al.*, 1978; Morris, 1970). Most studies have included only small particles – those that can be collected by neuston nets (Austin & Stoops-Glas, 1977; Carpenter *et al.*, 1972; Carpenter & Smith, 1972; Colton *et al.*, 1974; Morris, 1980b; Van Dolah *et al.*, 1980). Only two shipboard studies refer to sightings of large pieces of plastic. Venrick *et al.* (1973) listed sightings of man-made objects (two-thirds of which were plastic) on the surface of the central north Pacific in an area 600 miles from the nearest landfall (Hawaii) and outside main shipping lanes, while Morris (1980a) found that in the Mediterranean, where pollution of this type could be expected to be high for both oceanographic and demographic reasons, 60–70% of objects over 1.5 cm in size appeared to be plastic debris such as bottles, sheets, cups, packing material, etc. In addition, beach studies of marine litter (including plastic containers and plastic fragments) have been carried out on British and West European beaches, where a large proportion of litter was found to originate from shipboard sources (Dixon & Dixon, 1981).

Table 1 shows plastic material obtained in one collection along the hightide line over approximately ½ mile of the North Beach, Fort Pierce, Florida, on 23 December 1980, after several days of onshore winds. This sample included only those items (76) encrusted by at least one bryozoan colony; the total number of items present was at least double that number. Most of this material (51 items) consisted of whole or parts of plastic containers or container tops. Most items (47) were semi-flexible, though some had become brittle apparently due to breakdown of the plasticizers with age (Carpenter & Smith, 1972). Composition included high density polyethylene, polystyrene and styrene butadiene rubber. Re-flotation in seawater showed that most pieces (62) had floated at or just below the water surface.

Probably many of these objects were swept into the *Sargassum* windrows which form along the borders of convection cells at the ocean surface (Faller & Woodcock, 1964), and, thus entangled, cast ashore with the *Sargassum* masses. Their origin for the most part is not in the Sargasso Sea. Labels or imprinting with the place of manufacture aided in identification of the origins of some of these objects (though of course it does not preclude their having been dumped far away at sea!). Sources for some may be similar to those reported for pelagic tar in these waters (Cordes *et al.*, 1980; Van Dolah *et al.*, 1980). Twenty items

**TABLE 1**

Characteristics of drift plastic encrusted by bryozoans.

| Type of object | No. of items |
|---|---|
| Smaller bottles (bleach, detergent, etc.) | 13 |
| Container lids or caps (e.g. spray can tops) | 14 |
| Gallon jugs (e.g. milk jugs) | 8 |
| Bailers (gallon jugs cut in half | 7 |
| Other containers (e.g. ice cream, motor oil, baby formula) | 9 |
| Washtubs and buckets | 9 |
| Plates, cups, bowls | 4 |
| Sandals | 3 |
| Plastic lattice | 2 |
| Plant pot | 1 |
| Regulator exhaust port | 1 |
| Toy | 1 |
| Chemical toilet base | 1 |
| Paint brush handle | 1 |
| Boat rudder | 1 |
| Unidentifiable fragments | 1 |
| Total | 76 |
| **Buoyancy in seawater** | **No. of items** |
| Surface | 62 |
| Bottom | 14 |
| **Flexibility** | **No. of items** |
| Rigid | 9 |
| Semi-rigid | 47 |
| Flexible | 20 |
| **Place of manufacture (stamped or labelled)** | **No. of items** |
| No identifying mark | 47 |
| United States | 20 |
| Venezuela | 4 |
| Colombia | 1 |
| In Spanish – no other identification | 2 |
| England | 1 |
| Sweden | 1 |
| **No. of bryozoan species encrusting** | |
| 1 species only | 62 |
| 2 species | 8 |
| 3 species | 5 |
| >3 species | 1 |

could be identified as of US origin; it seems likely that these originated in southern Florida or in shipping traffic passing through the Straits of Florida, were carried through the Straits of Florida and entrained in the Florida Current–Gulf Stream system. It is possible that some US debris had a more distant source in the Gulf of Mexico and was carried by the Gulf Loop current to the Straits of Florida, but in view of the evidence on pelagic tar transport this is probably a less important source. Plastic items originating in Venezuela, Colombia, Guatemala and Jamaica were also found in the sample, indicating that the other major source of the plastic is the Caribbean. Material transported from the easternmost Caribbean and the northern coast of South America could reach the Atlantic coast of Florida via the Guiana and Antilles Currents. Material originating in the southern or southwest part of the Caribbean would be carried by the Caribbean Current, passing south of Jamaica and between the Yucatan Peninsula and the west coast of Cuba, through the Straits of Florida and into the Gulf Stream. Calculations based on July surface currents (as given in Wüst, 1964) indicate that an object could be transported by this route from Venezuela to the Atlantic coast of Florida in as little as four months, or from Jamaica to the Atlantic coast of Florida in as little as two months.

Like *Sargassum,* drifting plastic become a substratum for encrusting organisms, but while the *Sargassum* community consists of over 100 species, 10% of them endemic, and shows a high degree of biological integration, with specialized adaptations of form and behaviour that indicate a relatively long history (Friedrich, 1969), the fauna and flora of drift plastic is limited to a very few species (of bryozoans, serpulids, barnacles, *Millepora,* filamentous algae and Foraminifera), and at least in the area studied is dominated by the encrusting cheilostome bryozoan *Electra tenella* (Fig. 1). *Electra tenella* occurred on 56 of the objects sampled, and on 43 of them it was the only bryozoan present. The second most abundant species, *Membranipora tuberculata,* is the commonest bryozoan and one of the most abundant organisms on *Sargassum* (Friedrich, 1969; Ryland, 1974). Although larvae show settlement preferences on *Sargassum natans,* the species can occur on other algae (Winston & Eiseman, 1980), and it is not surprising to find some colonies on plastic substrata. *Electra tenella,* however, has not been found on *Sargassum.* It may be that settling larvae of *E. tenella* cannot attach to the *Sargassum* surface, or dislike the tannins it produces, or that the species cannot survive the competition for space in the densely populated *Sargassum* community. When *M. tuberculata* and *E. tenella* colonies came into contact with each other on plastic surfaces the *M. tuberculata* overgrew the *E. tenella.* The reason for the success of *Electra tenella* on plastic may lie in the lack of ability of most other organisms to colonize the smooth semi-flexible plastic surfaces, or to grow and persist without being sloughed or broken. There may also be far less predation occurring around floating plastic objects than in the *Sargassum* community where filefish, flatworms, pycnogonids and nudibranchs all feed on bryozoans.

*Electra tenella* was described by Hincks (1880) based on a specimen collected from Florida. Since then it has been re-described only by Marcus (1937) who found it on the coast of Brazil, and Weiss (1948) who reported it (as *Acanthodesia tenella*) from fouling panels in Biscayne Bay, Miami Beach, Florida. Osburn (1940) stated that he did not find the species in Puerto Rico, but examination of his specimens of *'Conopeum reticulum'* showed them to be *Electra tenella* and not the European species *Conopeum reticulum.* This report listed it as occurring on hard substrata, chiefly dead shells and barnacles in shallow water harbour areas, but it has only once been recorded as a fouling species (Weiss, 1948). Perhaps, like the closely related Indo-Pacific species *Electra angulata* (recorded from drifting wood, from shells, barnacles and sea-snakes), *Electra tenella* has specialized for an epipelagic mode of life.

In spite of its sparse record over the last hundred years, *Electra tenella* is now one of the most abundant bryozoans on the Atlantic coast of Florida (Winston, 1982), and its success appears to be due chiefly to the presence of large quantities of drift plastic in those waters. The increase in the amount of semi-rigid or non-algal epipelagic substratum provide by plastic trash may have been somewhat offset by a decrease in the available natural substratum (logs, non-finished wood, coconuts, sea beans), due to the clearing of coastal forests and development of coastal areas. But the total amount of plastic substratum is probably increasing rapidly and will continue to do so, at least in the near

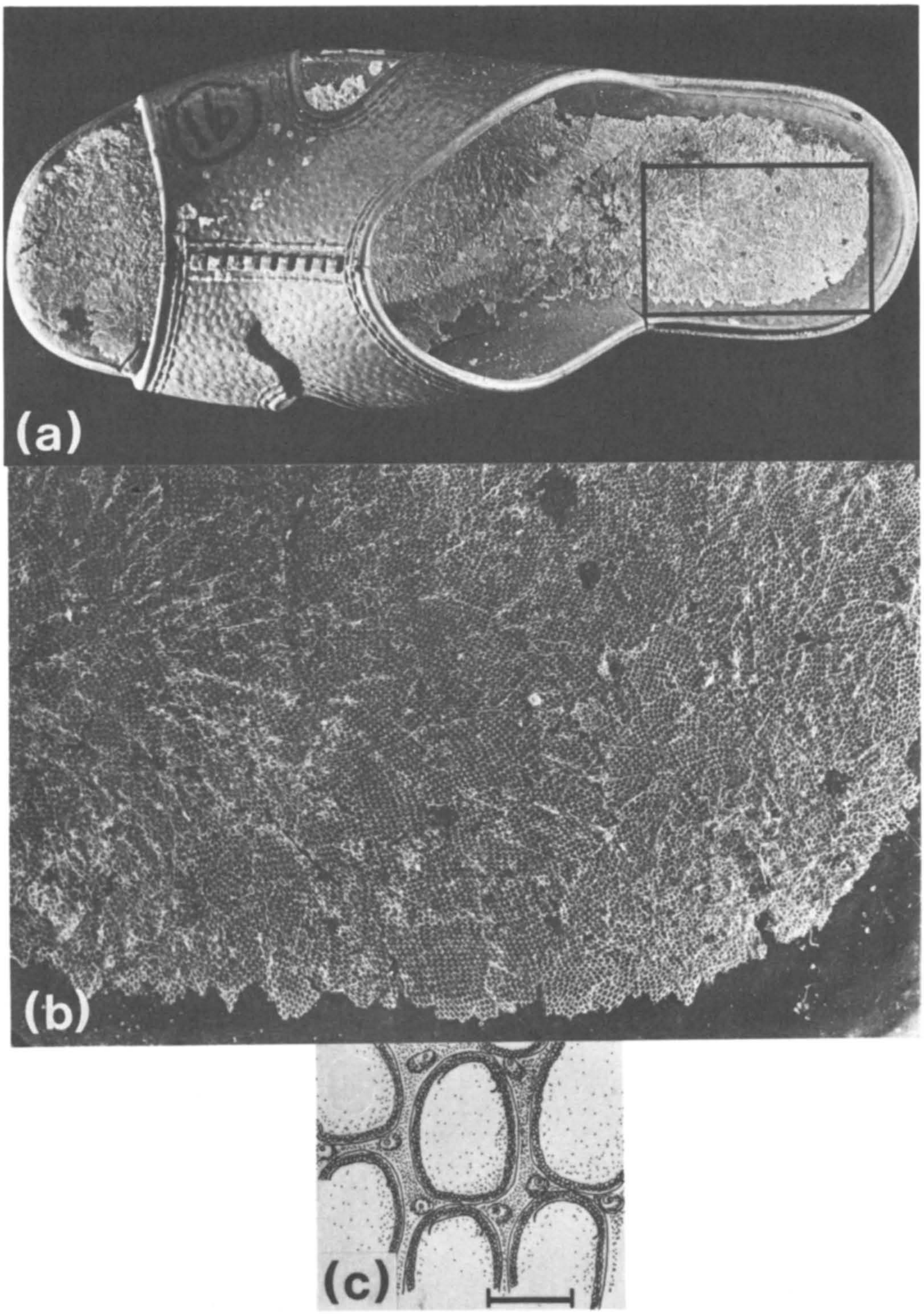


**Fig. 1** (A) Sandal of Colombian manufacture encrusted by colonies of the chielostome bryozoan *Electra tenella*. 4 × 6 cm area enclosed in black rectangle is enlarged in Fig. 1B.
(B) Portions of two colonies of *Electra tenella*.
(C) Several zooids of *Electra tenella* (scale = 200 μm).

future, as Caribbean countries increase production and distribution of plastics. Like other organisms able to thrive in the border of manmade and natural environments (e.g. wild turkeys, cattle egrets, armadillos) this marine invertebrate may be actively expanding its abundance and range.

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Austin, H. M. & Stoops-Glas, P. M. (1977). The distribution of polystyrene spheres and nibs in Block Island Sound during 1972–1973. *Chesapeake Sci.*, **18**, 89–92.

Butler, J. N., Morris, B. F. & Sass, J. (1973). Pelagic Tar from Bermuda and the Sargasso Sea. Special Publication No. 10, Bermuda Biological Station.

Carpenter, E. J. & Smith, K. L. (1972). Plastic on the Sargasso Sea surface. *Science*, **175**, 1240–1241.
Carpenter, E. J., Anderson, S. J., Harvey, G. R., Miklas, H. P. & Peck, B. P. (1972). Polystyrene spherules in coastal waters. *Science*, **178**, 749–750.
Colton, J. B., Knapp, F. D. & Burns, B. R. (1974). Plastic particles in the surface water of the northwestern Atlantic. *Science*, **185**, 491–497.
Cordes, C., Atkinson, L., Lee, R. & Blanton, J. (1980). Pelagic tar off Georgia and Florida in relation to physical processes. *Mar. Pollut. Bull.*, **11**, 315–317.
Dixon, T. R & Dixon, T. J. (1981). Marine litter surveillance. *Mar. Pollut. Bull.*, **12**, 289–295.
Faller, A. J. & Woodcock, A. H. (1964). The spacing of windrows of sargassum in the ocean. *J. mar. Res.*, **22**, 22–29.
Fowler, S. W. & Elder, D. L. (1978). PCB and DDT residues in a Mediterranean pelagic food chain. *Bull. envir. Contam. Toxic.*, **19**, 244–249.
Friedrich, H. (1969). *Marine Biology*. University of Washington Press, Seattle.
Giam, C. S., Chan, H. S. & Neff, G. S. (1978). Phthalate ester plasticizers, DDT, DDE and polychlorinated biphenyls in biota from the Gulf of Mexico. *Mar. Pollut. Bull.*, **9**, 249–251.
Hincks, T. (1880). Contributions towards a general history of the marine Polyzoa. II. Foreign Membraniporina (cont.) *Ann. Mag. Nat. Hist.*, ser. 5, **6**, 376–381.
Marcus, E. (1937). Bryozoarios marinhos brasileiros, I. *Bol. Fac. Fil. Ciênc. Letr., Univ. Sao Paulo*, Vol. 1, *Zoologia*, No. 1, 1–224.
Morris, R. J. (1970). Phthalic acid in the deep sea jellyfish *Atolla*. *Nature, Lond.* **227**, 1264.
Morris, R. J. (1980a). Floating plastic debris in the Mediterranean. *Mar. Pollut. Bull.*, **11**, 125.
Morris, R. J. (1980b). Plastic debris in the surface waters of the South Atlantic. *Mar. Pollut. Bull.*, **11**, 164–166.
Osburn, R. D. (1940). Bryozoa of Puerto Rico with a resume of the West Indian bryozoan fauna. *N.Y. Acad. Sci., Sci. Survey Porto Rico and Virgin Islands*, **16**, 321–486.
Ryland, J. R. (1974). Observations on some epibionts of gulf-weed, *Sargassum natans* (L.) Meyen, *J. exp. mar. Biol. Ecol.*, **14**, 17–25.
Van Dolah, R. F., Burrell. V. G. & West, S. B. (1980). The distribution of pelagic tars and plastics in the South Atlantic Bight. *Mar. Pollut. Bull.*, **11**, 352–356.
Venrick, E. L., Backman, T. W., Bartram, W. C., Platt, C. J., Thornhill, M. S. & Yeates, R. E. (1973). Man-made objects on the surface of the Central North Pacific Ocean. *Nature, Lond.*, **241**, 271.
Weiss, C. M. (1948). The seasonal occurrence of sedentary marine organisms in Biscayne Bay, Florida. *Ecology*, **29**, 153–172.
Winston, J. E. (1982). Marine bryozoans (Ectoprocta) of the Indian River Area, Florida. *Am. Mus. Nat. Hist. Bull.* **173**, 99–176.
Winston, J. E. & Eiseman, N. J. (1980). Bryozoan-algal associations in coastal and continental shelf waters of eastern Florida. *Fla. Sci.*, **43**, 65–74.
Wüst, G. (1964). *Stratification and circulation in the Antillean-Caribbean Basins*. Part I. Columbia Univ. Press, New York.

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# Correlation of Dispersant Effectiveness and Toxicity of Oil Dispersants Towards the Alga *Chlamydomonas reinhardti*

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**Using synchronous cultures of the unicellular green alga *Chlamydomonas reinhardti*, the toxicities of mixtures of Ekofisk crude oil and oil dispersants were measured. Sixteen so-called concentrates and 10 solvent-based dispersants were tested. The dispersing effectiveness of these compounds with respect to the Ekofisk crude oil was also measured. The concentrates were tested undiluted as well as diluted using algal growth medium (2‰ salinity) and artificial sea water (33‰ salinity) as dispersing liquid. The solvent-based compounds were tested in algal medium. For all compounds we found significant correlations between their toxicity and their effectiveness in dispersing the Ekofisk oil, such that the more effective the compound, the more toxic it was.**

To control the use of chemical oil dispersants in Norwegian waters, the Norwegian authorities have put forward regulations including toxicity testing with the green alga *Chlamydomonas reinhardti* (Anon., 1980). For several years we have been testing the toxicity of dispersants, both water-soluble concentrates and solvent-based types, with this alga and its close relative, the marine flagellate *Dunaliella bioculata*. During these studies we have noticed that the most toxic compounds seemed to be those which were the most effective in dispersing oil. This impression stems from visual observations of their effectiveness as seen in the algal cultures during testing, and from the observations that the mixture of oil and dispersant was usually more toxic than the two tested alone.

We here report the results of experiments undertaken to test whether or not such a correlation exists between toxicity and effectiveness.

## Methods

The test oil was Ekofisk crude oil, and the dispersants were commercially available ones obtained from the manufacturers. In this report they are not identified.

Toxicity tests were performed with synchronous cultures of *Chlamydomonas reinhardti*, as described previously (Heldal *et al.*, 1977). In short, appropriate amounts of oil/dispersant mixture were added to the algal cultures contained in 25 ml test tubes, to give a concentration series. These cultures consisted of zoospores at a density of *ca* 1.5 million cells $ml^{-1}$, and they were cultivated in parallel with control cultures at 35°C and at 20 000 lux, with intermittent